Neutron-antineutron oscillation in MicroBooNE

Jennet Dickinson

May 28, 2014

Neutron-antineutron oscillation

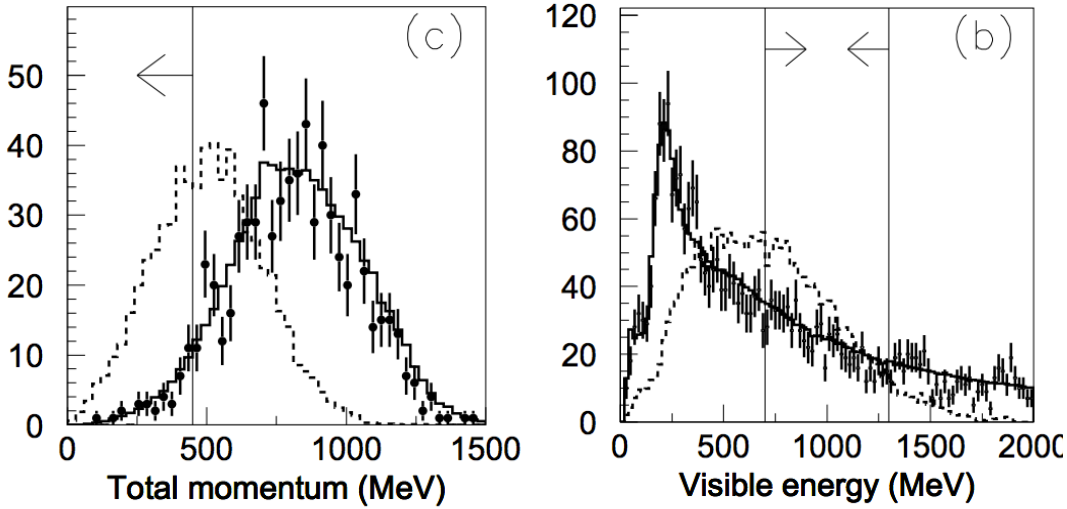
- A neutron (either free or bound in a nucleus) suddenly oscillates to an antineutron
  - Lower limits on oscillation lifetime from Super K: 1.89×10^{32} years for n bound in oxygen, 2.44×10^{8} seconds for free n
- This process violates conservation of baryon number
  - $\Delta B = 2$
- If n-$\bar{n}$ oscillation happens in a nucleus, the $\bar{n}$ annihilates with one of the surrounding nucleons, producing a spray of pions
  - Momentum ≈ 0, Energy ≈ 2GeV

Searching for n-$\bar{n}$ oscillation

- Neutrino detectors are the perfect place to search for rare processes like n-$\bar{n}$ oscillation
  - Low cosmic ray background (underground)
  - Large detector volume
- As a small surface detector, MicroBooNE will not be able to make competitive measurements/ place competitive limits on n-$\bar{n}$ oscillation
- Future multi-kiloton LArTPCs will! Studying the signature in MicroBooNE will be useful for this

n-$\bar{n}$ oscillation in Super K

- September 2011: The Search for n-$\bar{n}$ oscillation in Super Kamiokande I (arXiv 1109.4227)
- Super K is a water Cherenkov detector ➔ look for n-$\bar{n}$ oscillation in oxygen



Solid: atmospheric ν background

Dashed: n-$\bar{n}$ oscillation

- Average visible energy is 700 MeV < 2 GeV! (many reasons for this; large contributions by Cherenkov threshold effects)

n-$\bar{n}$ oscillation in Super K

- 12.1% detection efficiency for n-$\bar{n}$ oscillation events
- Saw 24 candidate events. 24.1 background events were predicted
- Super K places cuts on:
  - Number of Cherenkov rings, total momentum, total visible energy, and invariant mass
  - Additional cuts to be explored: http://www.nevis.columbia.edu/reu/2011/AyoubReport.pdf

A LArTPC could potentially improve on this

Simulating n-$\bar{n}$ oscillation in MicroBooNE

- We approximate n-$\bar{n}$ oscillation by simulating $\bar{n}$-nucleon annihilation in MicroBooNE
  - Does not include intra-nuclear interactions of final state particles
  - Does not take into account the breakup of the Argon nucleus
- A more thorough study would need to include these effects – especially since we expect them to be more pronounced in Ar than in O
  - Work already being done modeling these intra-nuclear effects (LBNE docdb #8940)

$\bar{n}$-nucleon annihilation generator

- Available in the uboone offline repository:
  - https://cdcvs.fnal.gov/redmine/projects/ubooneoffline/repository/show/users/jennetd
- Generates final states according to these branching ratios (arXiv 1109.4227):

$\bar{n}+p$		$\bar{n}+n$	
$\pi^+\pi^0$	1%	$\pi^+\pi^-$	2%
$\pi^+2\pi^0$	8%	$2\pi^0$	1.5%
$\pi^+3\pi^0$	10%	$\pi^+\pi^-\pi^0$	6.5%
$2\pi^+\pi^-\pi^0$	22%	$\pi^+\pi^-2\pi^0$	11%
$2\pi^+\pi^-2\pi^0$	36%	$\pi^+\pi^-3\pi^0$	28%
$2\pi^+\pi^-\omega$	16%	$2\pi^+2\pi^-$	7%
$3\pi^+2\pi^-\pi^0$	7%	$2\pi^+2\pi^-\pi^0$	24%
		$\pi^+\pi^-\omega$	10%
		$2\pi^+2\pi^-2\pi^0$	10%

Ratio of $\bar{n}$-p to $\bar{n}$-n annihilations is 1.63, scaled from ratio measured in deuterium

Does the generator work?

We generated 2500 events. Resulting final states match up well with the branching ratios we input:

$\bar{n}+p$			$\bar{n}+n$		
Final State	Predicted	Observed	Final State	Predicted	Observed
$\pi^+\pi^0$	9.5 ± 6.1	11	$\pi^+\pi^-$	31 ± 11	23
$\pi^+2\pi^0$	76 ± 17	66	$2\pi^0$	23 ± 9.4	23
$\pi^+3\pi^0$	95 ± 19	105	$\pi^+\pi^-\pi^0$	101 ± 20	114
$2\pi^+\pi^-\pi^0$	209 ± 27	200	$\pi^+\pi^-2\pi^0$	171 ± 25	175
$2\pi^+\pi^-2\pi^0$	342 ± 35	345	$\pi^+\pi^-3\pi^0$	434 ± 41	420
$2\pi^+\pi^-\omega$	152 ± 24	153	$2\pi^+2\pi^-$	109 ± 20	114
$3\pi^+2\pi^-\pi^0$	67 ± 16	71	$2\pi^+2\pi^-\pi^0$	372 ± 37	385
			$\pi^+\pi^-\omega$	155 ± 24	149
			$2\pi^+2\pi^-2\pi^0$	155 ± 24	146

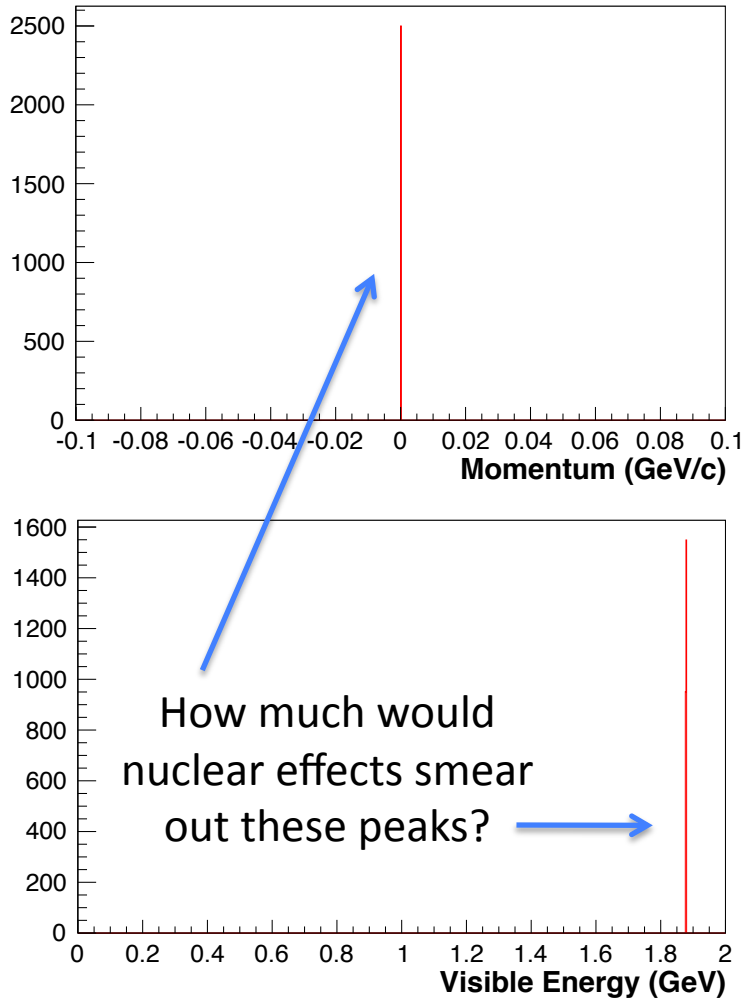
✔ Ratio of $\bar{n}$-p to $\bar{n}$-n annihilations is 1.63, as expected

Does the generator work?

We can look a the total energy & momentum of the final state particles

✔ Total momentum is 0

✔ Total energy is either
1.879 GeV ($2m_n$) or
1.877 GeV ($m_n + m_p$)

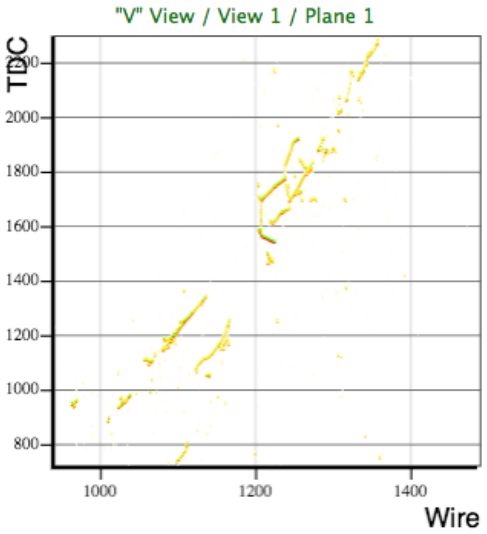


The generated events

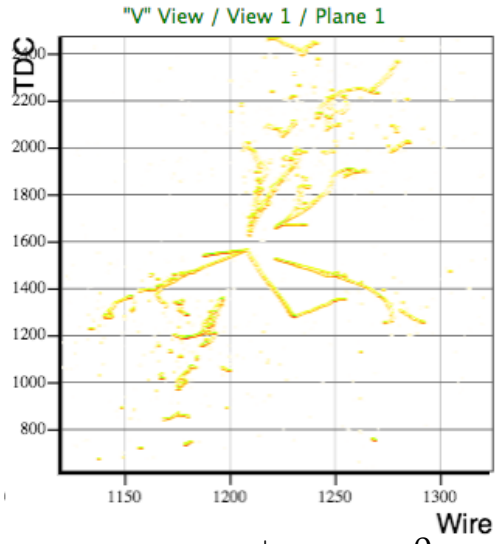
- On average, these events have
  - 2.8 charged pions
  - 1.4 neutral pions
  - 4.2 final state pions (both charged and neutral)
  - Note: this doesn't include the decay products of ω
  - Note: we expect the number of pions exiting the nucleus to be diminished by nuclear effects

- We can import the generated final states into LArSoft and look at the event topology

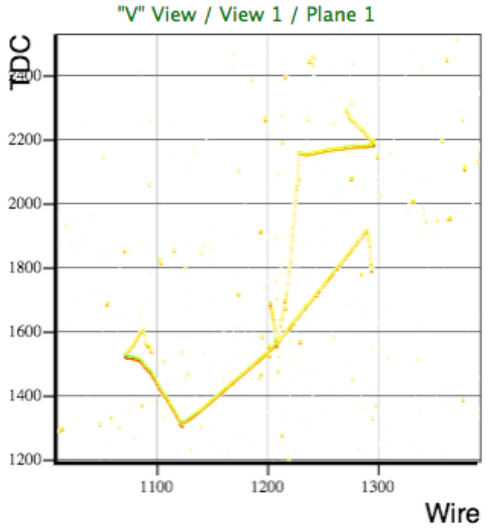
Example events



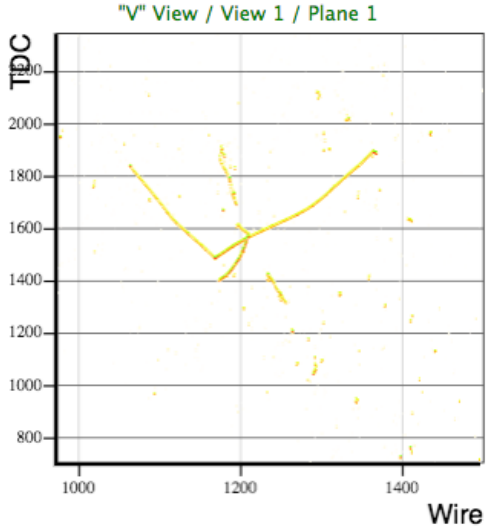
$n\bar{n} \to \pi^+\pi^- 2\pi^0$



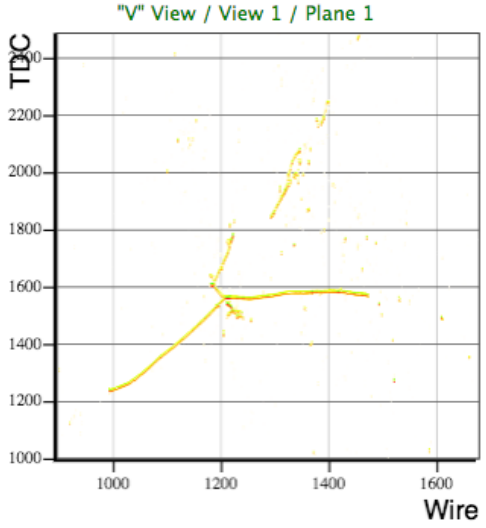
$n\bar{n} \to \pi^+\pi^- 3\pi^0$



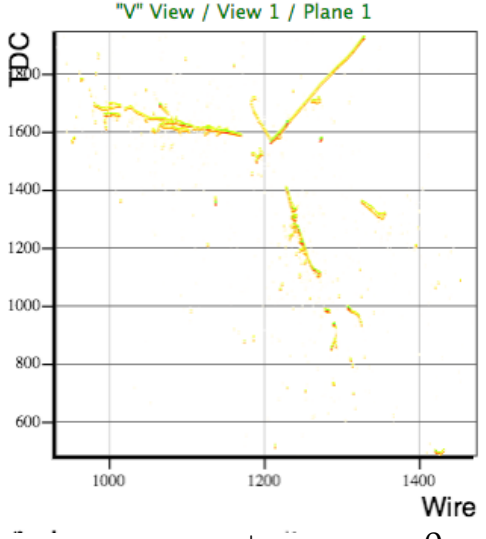
$n\bar{n} \to 2\pi^+ 2\pi^-$



$n\bar{n} \to 2\pi^+ 2\pi^- \pi^0$

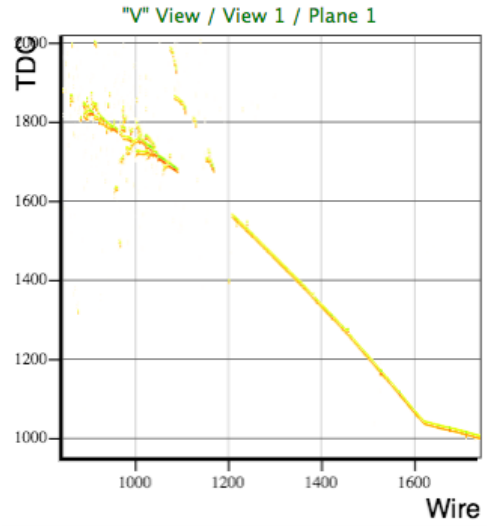


$n\bar{n} \to \pi^+\pi^-\omega$

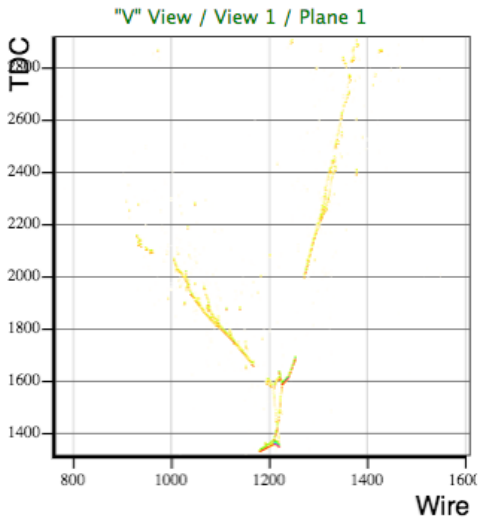


$n\bar{n} \to 2\pi^+ 2\pi^- 2\pi^0$

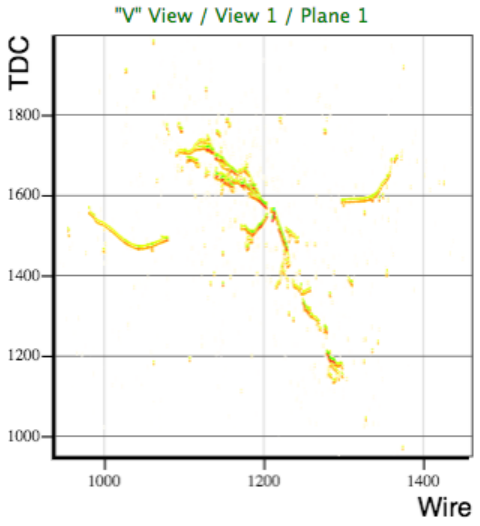
Example events



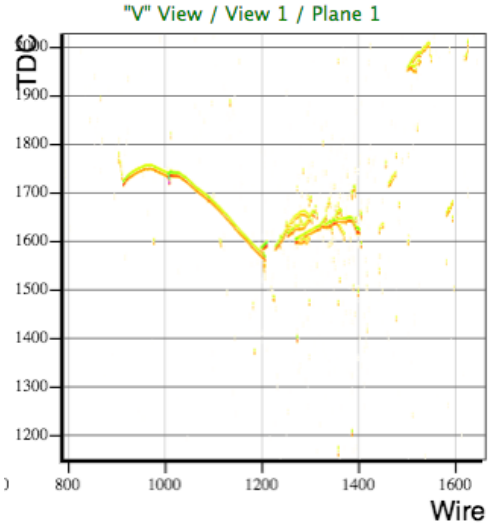
$p\bar{n} \to \pi^+\pi^0$



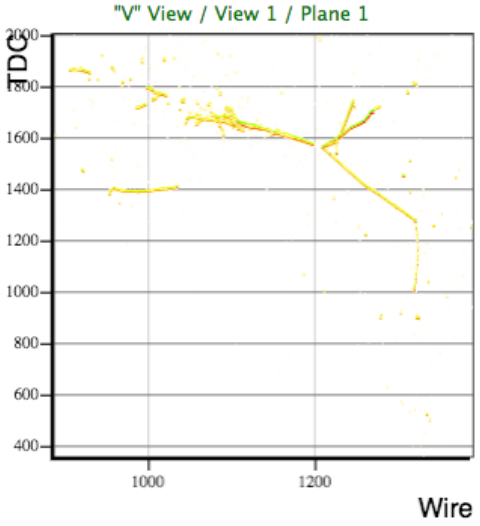
$p\bar{n} \to \pi^+2\pi^0$



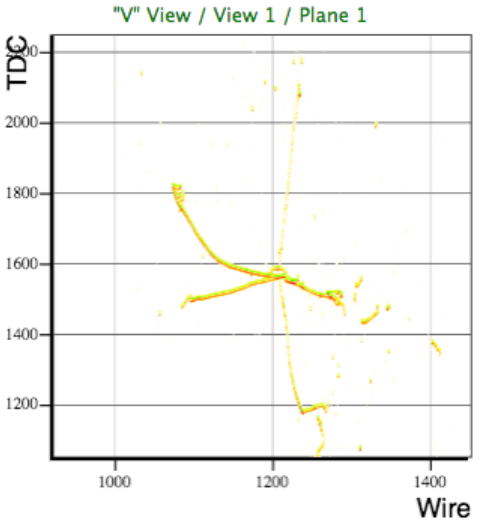
$p\bar{n} \to \pi^+3\pi^0$



$p\bar{n} \to 2\pi^+\pi^-\pi^0$

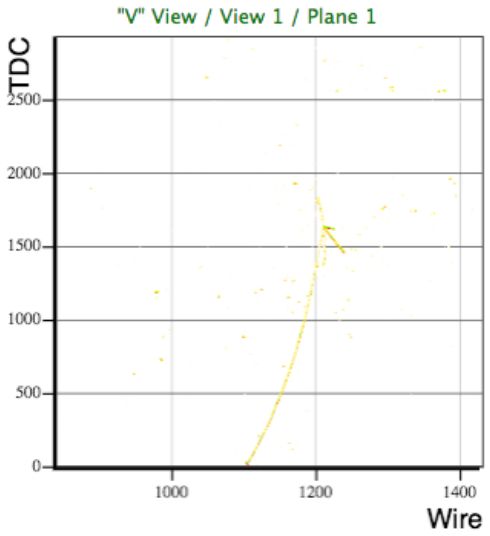


$p\bar{n} \to 2\pi^+\pi^-2\pi^0$

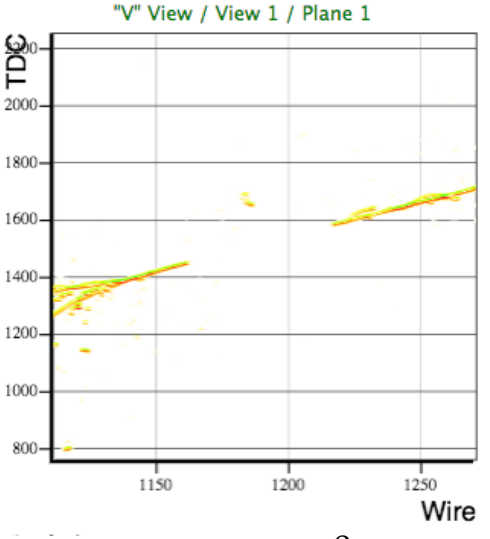


$p\bar{n} \to 2\pi^+\pi^-\omega$

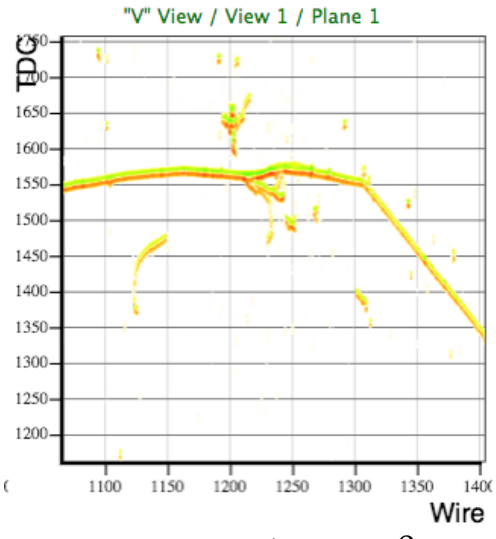
Example events



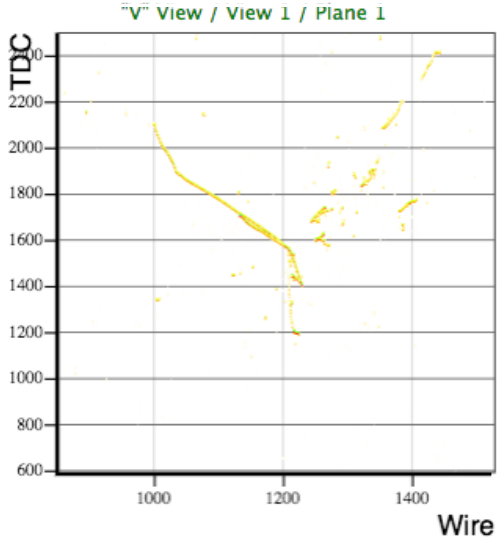
$n\bar{n} \to \pi^+\pi^-$



$n\bar{n} \to 2\pi^0$



$n\bar{n} \to \pi^+\pi^-\pi^0$



$p\bar{n} \to 3\pi^+2\pi^-\pi^0$

Summary & Next Steps

- The generator is ready to use! Example events exist
- Can begin working on reconstruction of these events
  - Requires good multi-track/shower event reconstruction and good shower/track separation
- Can study signal efficiency optimization
- Can do similar studies of cosmogenic backgrounds